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Sustainable energy future via grid interactive operation of spv system at isolated remote island

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ABSTRACT

This paper has analyzed the case of Moushuni Island at Sundarban of 24 Parganas South of West Bengal, India. The proposition is to find out the possibility of grid-connectivity of Isolated Remote Island which is under rural electrification scheme by hybrid renewable energies under Jawaharlal Nehru National Solar Mission of India. In these rural electrification program, grid extension can be the best option if the grid is reliable, the rural community rather big and in proximity to the grid. In many circumstances, a strong case for mini-grids based on hybrid systems can be made. Scattered communities and isolated houses are well served by solar and small hydro (where available) or small wind energy systems. By feeding renewable electricity to the utility grid through the grid-connected hybrid renewable energy system, during time of peak demand, sufficient electrical loads can be shed to prevent turning on a coal or natural gas-fired plant and therefore save CO_2 emissions and potentially energy import costs, replacing fossil fuels. The Social, Economic, and Environmental Benefits can be achieved through this proposition. Also, the Grid Interactive Operation of SPV System at Moushuni Island is tested. Malda district of West Bengal, India is a vision towards smart-grid city towards sustainable future, where rural consumers can upgrade their quality of life through solar energy resource.

Contents

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1. Introduction

The European Renewable Energy Council (EREC)—the umbrella organization of major European renewable energy industry, trade and research associations-recently prepared a report, ‘RE-thinking 2050’ which outlines a visionary pathway towards a 100% renewable energy supply system for the European Union by 2050.

In order to ensure a truly sustainable energy future for the European Union (EU), it is necessary to put in place the right policies and ensure their implementation. Some of the measures include: setting binding energy efficiency targets and preparing a roadmap to reduce energy demand, drawing up effective renewable energy targets for 2030, liberalizing the energy market, phasing out all subsidies for fossil fuel and nuclear energy, and introducing an EU-wide carbon tax. An integrated electricity infrastructure merging the concept of ‘Super Grid’ with that of ‘Smart-Grid’, hybrid energy solutions and setting up virtual power plants, bringing about revolutionary changes in the transport sector, building energy efficient buildings and smart-energy cities etc.

1.1. Economics-positive factors of grid-connectivity

(i) Net metering;
(ii) distributed applications (utilities place solar generating capacity closer to new high-demand areas to avoid building new transmission facilities and large plants);
(iii) green marketing;
(iv) solar roof initiative(US Department, of energy program mandating government procurement of solar energy systems, streamlining relevant federal loan programs and offering other inducements to use solar energy);
(v) portfolio standards (regulations mandating that utilities provide a set percentage of electricity from particular renewable sources);
(vi) good for remote areas where extending the grid expensive and
(vii) efficient use of land for the roof top system.

By feeding renewable electricity to the utility grid through the grid-connected hybrid renewable energy system, during time of peak demand, sufficient electrical loads can be shed to prevent turning on a coal or natural gas-fired plant and therefore save CO_2 emissions and potentially energy import costs.

1.2. Social, economic, and environmental benefits

A sustainable energy economy offer not just ecological benefits, but social and economic benefits too. The foremost benefit of deployment of renewable energy technologies is employment generation called ‘green job’. The renewable energy industry offers a variety of highly skilled and semi-skilled jobs and the sector is highly employment intensive. In India, if we sincerely implement the 15% RE target set by NAPCC, we could have to add 90, 000 MW of additional renewable power upto 2020. At an average of 20 jobs per MW (both direct and indirect) addition of 90, 000 MW of renewable capacity can create 1.8 million jobs. Energy security and autonomy would be the major economic benefit due to freedom from fossil fuels. Import dependency exposes us to major price since fossil fuels are globally traded commodities. It also makes us vulnerable to any disruption in supply. These risks are real, judging from events from the recent past. The biggest advantage of renewables is that there is no risk of fuel price volatility since the fuel source is a freely available natural resource, if by 2020, we have to produce 15% of our electricity requirements from the renewables, we will have to generate 246 billion units of electricity (15% of 1643 billion units in 2020, as per CEA projections). This would facilitate avoidance of approximately 24.6 million tones of CO_2 emissions per year. Substitution of coal and nuclear power with renewables can also avoid the huge environmental destructions caused by mining in the form of deforestation, land degradation, pollution of water bodies etc. implementation of a Renewable Energy Grand Plan will bring all-round benefits in the social, economic and environmental spheres. A sustainable future is not one of the choices facing us, but it is our only choice to ensure sustainable modernity.

1.3. Role of WBREDA in rural electrification in India

The proposition to connect the isolated remote hybrid renewable power plants to the conventional power grid is a challenge in the Indian scenario towards an aspect of sustainability.

West Bengal Renewable Developments Agencies (WBREDA) in Eastern part of India is trying to electrify remote isolated villages through hybrid renewable energies. As a part of National Solar Mission of India, decentralized hybrid renewable energy plants are already operating in isolated Moushuni Island of Sundarban of West Bengal eastern part of India. Also decentralized Solar Energy for village electrification has been implemented in India. Grid extension for these isolated remote islands or villages can be the best option if the grid is reliable, the rural community rather big and in proximity to the grid.

Principles for choosing a technology for rural electrification can be illustrated as: (i) Life cycle cost analysis: the cost-benefit analysis should span the whole lifecycle of a system, which can usually be considered to be 15–20 years. This analysis comprises the initial investment costs, operation costs (fuel, maintenance etc.) and replacement costs; (ii) the environmental dimension: the environmental dimension should be factored in on the basis of reasonable indicators, like CO_2 emissions; (iii) a long term perspective on fuel prices: the prices of fuel undergo dramatic changes based on the outlook of the economy. They have a strong speculative factor. Long term cost analysis should assume gradually growing international prices for oil; (iv) the socio-economic and cultural dimension: What level of organization exists within the community? Who are the leaders and are they willing to assume responsibility? Is it possible to spur local ownership? A rural electrification project should reach out to the people concerned right from the beginning; (v) local infrastructure: Are there technicians in the area? How can spare parts be transported? Are telecommunication facilities available?; (vi) technical requirements and improvement in energy efficiency: technical requirements of the system and measures to improve energy efficiency; (vii) break down of hybrid systems investment cost: hybrid systems have considerably higher initial investment costs. However, in many cases–such as this one–through lower operation costs they can break even after 8–12 years. The cost breakdowns depend on many variables, such as the natural conditions (wind speed/ solar irradiation), assumptions on the long term price of diesel, the configuration of the system, load profiles and assumptions on diesel generator and battery lives [6].

*Parameters for short-term and long-term load demand in rural electrification through renewable are: (i)*increasing or decreasing population; (ii)changing consumer trends (e.g. increased use and number of electrical appliances); (iii)special community events; (iv)seasonal changes of environmental conditions (e.g., temperature, humidity).

1.4. Optimization of hybrid renewable energy systems

Rural India will not get 40% electricity to 50% of time at the end of 13th plan. Hence, to make a 24 h reliable system for rural India, hybrid renewable energy systems must be optimized in the off-grid smart distribution system of remote isolated islands of Sundarban, West Bengal, India. Feasibility studies for optimization of hybrid renewable energy systems of solar, wind, bio-mass are required in the context of rural electrification of isolated remote islands of Sundarban of West Bengal eastern part of India. Bio-mass is scarce resource. Hence, reliability of power with minimum consumption of bio-mass or diesel is required for designing of smart energy system which is a hybrid of solar–wind–biomass. Evening 4 h rural load can be met with hybrid renewable energy system instead of feeding 24 h expensive conventional energies to the rural micro-grid, and if out of 18 h in a day, during 16 h day time, electricity is supplied by conventional power and rest 4 h in the evening, with hybrid renewable, the average cost of the electricity/hour will be reduced by feeding renewable through Intelligent Controller, proposed to be installed at remote isolated Moushuni Island of Sundarban, West Bengal eastern part of India.

2. Literature review of optimized hybrid renewable energy systems

The most intelligent controller is required for remote isolated islands of Sundarban, West Bengal eastern part of India, to design the optimized hybrid renewable energy system of solar–wind–biogas in off-grid distributed network and on-grid smart-energy system where the extra energy is feeding to the National Grid or vice-versa in on-grid where grid-integration is feasible. In this context, a literature review has been done to illustrate the background cases of the designing hybrid renewable energy system.

The optimization of hybrid energy systems in the context of minimizing excess energy and cost of energy is addressed by Razak et al. [1]. The high upfront cost hybrid systems warrants the need to optimize unit sizing for reliable and costeffective energy system [2,3]. Brandli and Dick [5] and Khan and Iqbal [9] used the Hybrid Optimization Model for Electric Renewables (HOMER) software [6] to find optimum sizing and minimizing cost for hybrid power system with specific load demand in standalone applications. These studies have however not addressed the optimization of the design and implementation of hybrid energy systems—optimized design solutions are not always implementable due to environmental constraints. In most cases optimization of the design and implementation of hybrid renewable energy systems is dependent on the geographic location and not just on the available renewable energy resource.

2.1. Sizing of a hybrid system of renewable energy for a reliable load supply without interruption

Souissi et al. [7] analyzed the sizing of a hybrid system of renewable energy for a reliable load supply without interruption, where a diesel generator used as auxiliary source and combined with the Wind–PV-battery hybrid system can ensure a reliable supply without interruption. Under this study, during system operation at any time interval, three situations are interpreted as:

(i) the total energy generated by the PV and wind generators can be greater than the load demand. In this situation, the energy surplus is stored in the batteries after calculating, as a preliminary, the maximum amount of energy that can be charged in the battery bank. The excess of energy, if there exists, is calculated for each hour;
(ii) the demand of the load can be greater than the total energy generated by the PV and wind generators: in this case, the load must be covered by the energy stored in batteries after calculating, as a preliminary, the maximum amount of energy that can be discharged from the battery bank. The deficit of energy, if there exists, is calculated for each hour;
(iii) the load demand can be equal to the total energy generated by the PV and a wind generator, the batteries capacity remains unchanged. The simulations results provided by HOMER prove that the combination of a diesel generator, as buck-up source, with the hybrid wind–PV-battery system is the best solution to guarantee the reliable supply without interruption of the load under the climatic data change by the greenhouse gas emissions led to an unstable climate and extreme meteorological phenomena like hurricanes, typhoons, storms, which can influences in a significant way on the reliable supply of the renewable energy sources The optimal sizing of the hybrid wind–PV-diesel-battery system is deduced from the two optimal configurations chosen: (wind–PV-battery) and (diesel-battery).

Sopian et al. [8] analyzed the optimization of the hybrid system in context of minimizing the excess energy and cost of energy. The hybrid of pico-hydro, solar, wind and generator and battery as back-up is the basis of assessment. The system configuration of the hybrid is derived based on a theoretical domestic load at a remote location and local solar radiation, wind and water flow rate data. Three demand loads are used in the simulation using the HOMER to find the optimum combination and sizing of components. Another set of demand loads is used to investigate the effect of reducing the demand load against the dominant power provider of the system. The results show that the cost of energy can be reduced to about 50% if the demand load is increased to the maximum capacity. Reducing the load to the capacity of the dominant power provider will reduce the cost of energy by 90%.

2.2. Pre-feasibility study of using hybrid energy systems with hydrogen as an energy carrier

A potential solution for stand-alone power generation is to use a hybrid energy system in parallel with some hydrogen energy storage. Khan and Iqbal [9] explained a pre-feasibility study of using hybrid energy systems with hydrogen as an energy carrier for applications in Newfoundland, Canada.

2.3. Hybrid power system to be used to reduce energy storage requirements

As per the analysis of Darus et al. [10] for hybrid (solar and wind) energy systems for rural electrification, the hybrid power system has been recommended to be used to reduce energy storage requirements. It has been found that the PV–wind hybrid option is techno-economically viable for rural electrifications when the PV module cost is below Rs 100 per Wp and the efficiency of PV module is higher than 20%. Also, the comparative cost of grid line extension energy source with the PV–wind hybrid system is a vital parameter to decide the viability of installing a PV–wind hybrid system. In this of the development of hybrid integrated renewable energy system (wind and solar) for sustainable living at Perhentian Island, Malaysia, concluded that the combination of solar panels, wind turbines and diesel generator would ensure continuous low electricity no matter what the weather conditions are.

In this context, the design of hybrid systems is a relevant issue. An ideal system has to supply, at any given time of the month, an instantaneous energy that equals the consumed energy by all system loads.

2.4. The DG lifecycle and the batteries lifecycle enlargement by a correctly designed PV–wind-diesel hybrid system

In another research, Fernandes and Figueiredo [11] emphasized that the diesel generator lifecycle as well as the batteries lifecycle could be enlarged by a correctly designed PV–wind–diesel hybrid system, when referring to the widespread off-grid generator systems. Both benefits need to be correctly accounted in the evaluation process, as maintenance costs are reduced significantly in the case of a PV–wind–diesel solution. A sub-sized system obviously does not satisfy the demand on electric power and, on the other hand, an over-sized system can be completely prohibitive due to economical and financial indicators [12,13]. This research aims to develop a new method to evaluate the design of a PV–wind–diesel hybrid system for electricity production. The different types of renewable sources are specifically evaluated in the economical performance of the overall equipment.

2.5. Wind–PV–high concentration photovoltaic (HCPV)-battery hybrid system via MIPC

Ou Ting-Chia and Huang Cong-Hui [14] studied the dc power supply system to combine with the hybrid renewable energy sources. The integration of the dc bus and a hybrid renewable power supply system is proposed. The proposed wind–PV–high concentration photovoltaic (HCPV)- battery hybrid dc source system is designed for general house, and it could connect the grid with dc household application. The main function of this system is to directly provide dc bus and loads with dc power which is generated by the wind–PV–HCPV battery hybrid system via the multi-input power converter (MIPC). A MIPC which operates in four types is proposed such as:

(i) an operation type wherein power is delivered to dc bus from hybrid renewable energy sources;
(ii) a single type wherein only one renewable energy source supplies power to the dc bus;
(iii) an inverter type wherein power is delivered to dc Bus from ac grid via inverter module;
(iv) a battery type wherein power is delivered to dc Bus from batteries without renewable energy source.

2.6. Use of a buck/boost converter to interface the storage device to the DC link increasing the power supplied by the renewable sources

In the optimization of a hybrid renewable energy system applied to a low power photovoltaic–wind plant it has been found that low power hybrid renewable energy systems are of great interest in the market due to the wide possibility of utilization, hence their optimization is particularly needed [15,16]. As a matter of fact, hybrid systems with PV/Wind energy sources and diesel generator [17,18], with or without batteries, are used regularly to satisfy the energy requirements of remote areas in a reliable and cost effective way [19]. In this context, the use of a buck/boost converter to interface the storage device to the DC link allows a significant increase in the power supplied by the renewable sources, thus maximizing the operating efficiency. The annual energy produced by the whole system is increased too.

2.7. A storage system made of batteries used for an efficient energy management in a hybrid renewable power system

Han et al. [20] analyzed a storage system made of batteries used for an efficient energy management in a hybrid renewable power system. A bidirectional DC–DC converter is used to charge or discharge the battery bank. In fact, the bidirectional DC/DC converter charges the battery bank for the buck operation. For a lead–acid battery, a multi-stage charger is needed. First the battery is charged at a constant current to a set voltage threshold. As the battery saturates, the current drops and charge voltage remain a constant. At last, the float charge compensates for the self discharge.

2.8. Resolving optimization problem by minimizing the net present cost (NPC) or, in relation to the levelized cost of energy (LCE)

Dufo-Lo ́ pez and Bernal-Agustı ́n [21] studied to resolve optimization problem in which the Net Present Cost (NPC) is minimized or, in some cases, in relation to the Levelized Cost of Energy (LCE) in the design of the most usual systems such as PV–wind-Battery and PV–diesel-Battery systems. The correct resolution of this optimization problem is a complex task because of the high number of variables and the non-linearity in the

performance of some of the system components. It has been determined that the most frequent systems are those consisting of a PV generator and/or wind turbines and/or diesel generator, with energy storage in lead–acid batteries. Energy storage in hydrogen, although technically viable, has a drawback in terms of its low efficiency in the electricity–hydrogen–electricity conversion process, besides the fact that, economically, it cannot compete with battery storage at the present time.

Dufo-Lo′pez and Bernal-Agustı′n [22] carry out the optimization of hybrid PV–diesel-Battery systems by means of Genetic Algorithms (GA). In a prior paper [23], they determined the correct performance of GA as a technique for the design of hybrid systems. Thus, by means of GA, the optimum or a very similar system to the optimum can be obtained, with reduced calculation time. The results obtained are compared in the optimization of a hybrid system applying GA with the results reached with an enumerative method (assessing all the possible designs).

There are many indications that there is a large potential market for the deployment of medium to large scale wind–diesel, PV–diesel and wind–PV–diesel hybrid power systems for rural electrification in various countries around the globe, and though there are an increasing number of demonstration projects but a true market for such systems has yet to emerge. Baring-Gould [32] outlined the foundations for hybrid power systems architecture and design and presented hybrid systems as an optimum approach for stand-alone power supply options for remote area applications.

Rehman and Al-Hadhrami [24] studies a PV–diesel hybrid power system with battery backup for a village being fed with diesel generated electricity to displace part of the diesel by solar. The HOMER sensitivity analysis showed that at a diesel price of 0.6$/l the cost of energy from hybrid system become almost the same as that of the diesel only system and above it, the hybrid system become more economical than the diesel only system. This paper recommended that a demonstration hybrid power system with 20% solar PV penetration should be developed and practical aspects of the development, operation, maintenance and thereof improvement should studied.

3. Objective of the Jawaharlal Nehru National Solar Mission (JNNSM) of India and regulatory framework

3.1. Objective

The objective of the Jawaharlal Nehru National Solar Mission (JNNSM) under the brand 'Solar India' is to establish India as a global leader in solar energy, by creating the policy conditions for its diffusion across the country as quickly as possible. The Mission has set a target of 20,000 MWand stipulates implementation and achievement of the target in 3 phases (first phase upto 2012–13, second phase from 2013 to 2017 and the third phase from 2017 to 2022) for various components, including grid connected solar power. The successful implementation of the JNNSM requires the identification of resources to overcome the financial, investment, technology, institutional and other related barriers which confront solar power development in India. The penetration of solar power, therefore, requires substantial support. The policy framework of the Mission will facilitate the process of achieving grid parity by 2022.

3.2. Regulatory framework for grid-connected rooftop SPV and other small solar power projects (100 kW–2 MW)

The JNNSM has outlined a separate regulatory framework for promotion of rooftop solar PV and small power plants, connected to LT/11 kV grid, to replace conventional power and diesel-based generators. The mission states that "the distribution utility will pay the tariff determined by the state electricity regulatory commission for thee metered electricity generated from such applications, whether consumed by the grid-connected owner of the roof-top/ground mounted installation or fed into the grid [30].

3.3. Regulatory framework for grid-connected Rooftop SPV and other small solar power projects (100 kW–2 MW)

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4. Literature review of optimized hybrid renewable energy systems

4.1. A. Solar home systems vs. grid-connectivity

Since rural electrification programs can easily over extend themselves, project appraisal needs to focus more attention on identifying the economic limits of extensions to the grid and on the economics potential of alternative energy sources, particularly solar energy (World Bank 1995b).

Most electrical utilities examine only grid-based options when planning their rural electrification programs. PV projects should be appropriately integrated into the rural electrification planning process as a least cost electrification option 1. From the users' perspective, electricity from a reliable distributed grid is preferable, as long as it is affordable. From the country's perspective, national economic policy dictates a least-cost path to energy service delivery. The rural electricity planner needs to know how to select the least-cost approach to delivering energy services at an accepted level of reliability and quality from among off-grid options for power supply, including sola home systems, kerosene and batteries and a grid-based power supply.

4.2. Economics of PV household electrification–a case study for effect of productive loads on break-even conditions–50 Wp solar home systems and a diesel-powered isolated grid in Indonesia

Indonesia, for example, the main sources of rural electricity are diesel engines serving isolated grids or large centralized generations that feed power to rural localities via medium–voltage transmission lines.

In Indonesia case study (case study commissioned by Asia Alternative Energy Unit–ASTAE, with the cooperation of the German BMZ/GTZ), three scenarios presented for villages located at varying distances from the existing grid, based on the assumptions, mentioned below:

(i) *Case1:* a remote area where the grid option is to construct an isolated grid produced by a diesel or a small hydroelectric plant.
(ii) *Case 2:* a village located 5 km from a medium–voltage (MV) line.
(iii) *Case 3:* a village located 3 km from a low-voltage (LV) line (the typical maximum distance for LV line extension).

The break-even point at which grid-based power supply and PV systems are equally cost-effective in this assessment depends

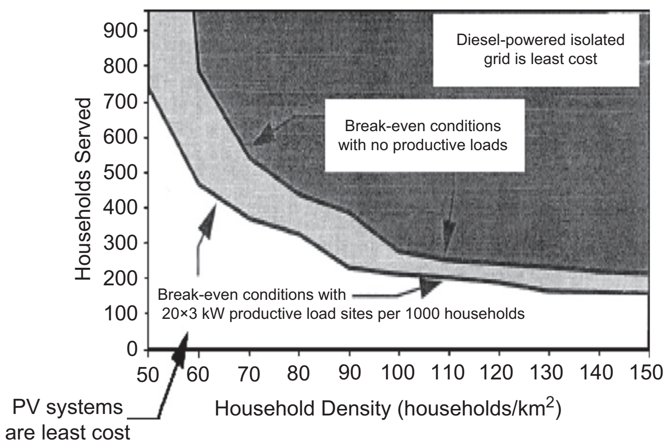

Fig. 1. Effect of productive loads on break-even conditions—50 Wp solar home systems and a diesel-powered isolated grid in Indonesia.

upon the size and density of the specific load to be served as well as the distance from LV and MV lines (See Fig. 1).

Assumptions:. (i) Level of service: (a) 8 h area lighting; (b) 6 h task lighting; (c) 60 Wh for other services. (ii) No load growth; (iii) 5 km distribution line per km^2 of grid service area(e.g., 100 households/km^2 = 20 households/km distribution line).

For example, solar home systems are least-cost economic option for a remote vilage with no productive loads, 400 households, and a household density of 80 households/km^2. However, an isolated grid would be the more economic option for the same village with 20×3 kW productive load sites for each 1000 households. Because, the cost of servicing productive loads with dedicated diesels (i.e., the solar home system alternative) exceeds the marginal cost of servicing the productive loads with the isolated grid, the economic niche for solar home systems is reduced. Therefore, if productive loads are likely for a particular village, they should be included in the electrification program.

4.3. Development of hybrid integrated renewable energy system (wind and solar) for sustainable living at Perhentian Island, Malaysia

The energy efficiency and renewable energy under the Eight Malaysia Plan (2001–2005) and Ninth Malaysian Plan (2006–2010) focused on targeting for renewable energy to be significant contributor and for better utilization of energy resources. An emphasis to further reduce the dependency on petroleum provides for more effort to integrate alternative source of energy. Aware at the potential of the harvesting the wind energy, Malaysian Government under Joint venture partnership with the State Government of Terengganu and National Electric Board in 2007 embark on the project of integrating power supply at Pulau Perhentian (Perhentian Island). The project consists of installing two wind turbine, solar farm (solar panel), generator and battery.

The main purpose of this project is to provide a reliable source for around the clock supply of electricity to the customer which is the people of Pulau Perhentian.

It is noted both wind turbine (WT1 and WT2) produce 18 kW each. Meanwhile the solar PV produce 39 kW. Total energy produce by RE farm is 75 kW. It was also noted that the site load requirement on that day is 71 kW. Therefore there is and access of 4 kW which will be stored in the battery. Therefore the energy produce by the two wind turbine will fulfill about 50% of load required with the average wind speed of 7.26 m/s [30].

5. Progress of grid-connected solar in the West Bengal, India

The first grid-connected 2 MW SPV power plant in the country was established in Asansol in West Bengal, India by the West Bengal Green Energy Development Corporation Ltd. in September 2009. The project was developed by Titan Energy Systems in collaboration with Beck Energy, Germany, at Jamuria near Asansol. The project which cost Rs. 36 crore got a soft loan from Power Finance Corporation (PFC). Power generated from the plant would be totally purchased by the Dishergarh Power Supply Corporation Ltd. (DPSCL) at Rs. 5 per kWh and a generation based incentive of Rs. 10 per kWh would be provided by MNRE. In the first year of its operation, the project generated 13 lakh units of electricity per MW. Two more crystalline silicon PV projects viz. 10 MW project by Videocon in Purulia district costing Rs. 150 crore and 5 MW project costing Rs. 70 crore by Astonfield in Bankura district are under development. Besides, West Bengal has 9 MW of installed capacity of off-grid solar projects. These include about 27 projects in the 50–100 kW range and about 1,70, 000 home-lighting systems.

The West Bengal State Electricity Regulatory Commission came up with a new renewable energy tariff order on 16 August, 2010. The Commission declared a tariff of Rs. 16.13 per kWh for grid-connected SPV projects (which are not eligible for any incentive declared by MNRE) commissioned up to 2012–2013 and the same shall remain valid for 25 years [31].

6. Connectivity options with grid in India

6.1. HVDC lines vs. smart-grid

Most of the India's grid-connected Concentrated Solar Power (CSP) generation would be in north-western India i.e. in Rajasthan and Gujrat. The existing system of alternating-current power lines won't be able to carry this DC power to load centers in northern and western India. Hence, it would be essential to build a high-voltage direct current (HVDC) power transmission network. HVDC line losses are much lower than AC lines, they are cheaper to build and require less land area then equivalent AC lines. The HVDC network would radiate from north-west to load centers in the north, north-west and western India. The line would terminate at converter stations where the power would be switched to AC and sent along existing regional transmission lines that supply customers. The implementation of the grid-connected renewable would require establishing a smart-grid network, with HVDC lines wherever required [30].

6.2. Guidelines for connectivity with the grid

The plant should be designed for interconnection with the State Transmission Utility (STU) at the voltage level of 33 kV or above. Further, the interconnections should be at the substation (substation should be 33 kV/132 kV or higher voltage levels) and not the distribution substation [31].

7. Proposed research in renewable energy resources—solar energy to develop a smart energy scenario to cut CO_2 emissions

The proposes methodology is considering following parameter such as: (a) identification of parameters such as: ***(i) economic***: cost of product, maintenance and operating cost, prevailing subsidy, tax benefits, benefit due to absence/lesser amount (than fossil-fuel-run equivalent system) of social/scarcity/opportunity cost, resale value, etc.—all in annualized quantities; ***(ii) social***: energy habit of the customer, social custom, esthetic value of the product, customers goodwill for reasons such as lowering

of pollution by use of these "green systems", political goodwill/propaganda, population density and accessibility of the location, grid connectivity, etc. and ***(iii) environmental:*** availability of solar radiation and other environmental conditions that would significantly affect the performance of the SPV system in consideration. *(b)* Quantification of each parameter should also take care of three levels of awareness of the target population, such as, ***(i) totally unaware; (ii) aware but not yet totally realized;*** and ***(iii) totally aware and realized.*** *(c)* A reasonable time frame based on: ***(i) estimated product-life; (ii) the life of the technology;*** and ***(iii) other factors*** (viz. the dynamic nature of the above mentioned parameters, the replacement frequency that depends on general habit of the users etc.). Quantification of each parameter should also take care of three levels of awareness of the target population, such as, **willingness for power-A: very willing; B: somewhat undecided; C: unwilling. Also considering supply time-A: 24 h supply; B: fixed time supply; C: any time supply** [see Appendix A Table 5 for another remote isolated island-Sagar Island distributes systems of Sundarbans, West Bengal, India]; (iv) **to identify the break-even point for integration; (b)technology upgradation: (i) creation of a standardized interface and testing of that interface regarding hybrid energy system integration; (ii) usage of A high-voltage, direct current (HVDC)** electric power transmission system: HVDC uses direct current for the bulk transmission of electrical power, in contrast with the more common alternating current systems. Also, for long-distance distribution, HVDC systems are less expensive and suffer lower electrical losses. Hence usage of HVDC in the context of renewable energy integration to electricity grid and vice-versa is proposed [27]; **(v) super conductor research:** this is encouraged as transmission loss is reduced while transmission through super conductor and hence this research in the context of renewable energy integration to electricity grid and vice-versa is proposed [27]; (c) incorporating NASA surface meteorology and solar energy data on solar energy resources to estimate the solar energy potential at a particular latitude and longitude) [25–28]; (d) select Renewable Energy and Energy Efficient Systems (REEESs) whose market potential is to be mapped. Priority to be given to systems which are more promising for large scale application but present utilization is far below the potential.; (e) identification of all relevant factors affecting the market potential or acceptance level for any new REEESs under consideration; (f) assess the significance level of each identified factor for the specific cases and assign the multiplication factor considering their availability, local, social and environmental conditions. Thus develop a scientific, elaborative, convenient and yet practically applicable method to calculate the Acceptance Index (AI) [25–28]; (g) collection of relevant primary data from representative number of locations distributed over the geographic region, viz. the eastern region of India. Test the kit with primary data so obtained for statistically representative locations. Make necessary modifications.

8. National action plan on climate change (NAPCC) by government of India

The National Action Plan on Climate Change promotes the development and use of solar energy for power generation, efficiency in energy and water use, afforestation of 6 million hectares of degraded forest lands and climate adaptation in agriculture. This will involve, for example, retiring inefficient coal-fired power plants and promoting renewable energy.

On June 30, 2008, Prime Minister Manmohan Singh released India's first National Action Plan on Climate Change (NAPCC) outlining existing and future policies and Programs addressing climate mitigation and adaptation. The plan identifies eight core "National Missions" running through 2017 and directs ministries to submit detailed implementation plans to the Prime Minister's Council on Climate Change by December 2008.Emphasizing the overriding priority of maintaining high economic growth rates to raise living standards, the plan "identifies measures that promote our development objectives while also yielding co-benefits for addressing climate change effectively." It says these national measures would be more successful with assistance from developed countries, and pledges that India's per capita greenhouse gas emissions "will at no point exceed that of developed countries even as we pursue our development objectives."

8.1. National Missions

National Solar Mission: the NAPCC aims to promote the development and use of solar energy for power generation and other uses with the ultimate objective of making solar competitive with fossil-based energy options. The plan includes:

(i) specific goals for increasing use of solar thermal technologies in urban areas, industry, and commercial establishments;
(ii) a goal of increasing production of photovoltaics to 1000 MW/year; and
(iii) a goal of deploying at least 1000 MW of solar thermal power generation.

Other objectives include the establishment of a solar research center, increased international collaboration on technology development, strengthening of domestic manufacturing capacity, and increased government funding and international support.

8.2. National Mission for enhanced energy efficiency

Current initiatives are expected to yield savings of 10,000 MW by 2012. Building on the Energy Conservation Act 2001, the plan recommends:

(i) mandating specific energy consumption decreases in large energy-consuming industries, with a system for companies to trade energy-savings certificates;
(ii) energy incentives, including reduced taxes on energy-efficient appliances; and
(iii) financing for public–private partnerships to reduce energy consumption through demand-side management programs in the municipal, buildings and agricultural sectors.

8.3. Case analysis of Moushuni Island to install grid interactive operation

West Bengal Renewable Development Agency (WBREDA) has set up a 53.5 kWp Solar PV power plant with an integrated daytime water supply system at village Bagdanga of Moushuni Island. Total population of this island is about 20,000. Primarily 300 families will be benefited with this power plant. Moushuni Island is a small picturesque island situated near Sagar Island and between Muriganga and Chinai rivers but very close to Bay of Bengal. *(A 20 kW Biomass Gasifier System is recommended to give back-up to this hybrid renewables system for a reliable electric supply during shortage of intermittent renewable like solar and wind).*

8.4. Objective of the project to install grid interactive operation of hybrid renewable energy system at Moushuni Island

(i) To install grid interactive operation of hybrid Solar Photovoltaic (SPV), wind and bio-mass systems at Moushuni Island.
(ii) To ensure the reliability and efficiency of the system to optimize the utilization of the hybrid renewable energy sources.

(iii) To design, fabricate and deply reliable power electronic fron-end interface with modular hardware.
(iv) This modular hardware is made indigenously for converting power output from multiple small-scale renewable energy sources and storage elements into usuable voltage and frequency levels [5].

The Intelligent Controller will switch from various renewable resources like solar–wind–biomass through change over switch panel to find out the optimized hybrid renewable energy system. The Intelligent Controller will extract the maximum energy input from the nature depending upon the seasonal change to feed to the distribution board to match between energy demand vs. energy supply. To make Capacity Utilization Factor (CUF) better, optimization is required. For this optimization, the second phase off-grid smart distribution system, is the designing of most Intelligent Controller (Fig. 4).

8.5. Problems

(i) The existing components in the existing system in Moushuni Islands for tapping sources like solar, biomass, wind etc. are not uniformly designed for integrated operation.
(ii) Issues of maintenance, service and spares tend to reduce availibility of these power plants.

Solutions: all interfaces need to be on a common AC link, which also serves as the feeder to the loads. A universal interface for hybrid renewable energy sources with technology for integrated

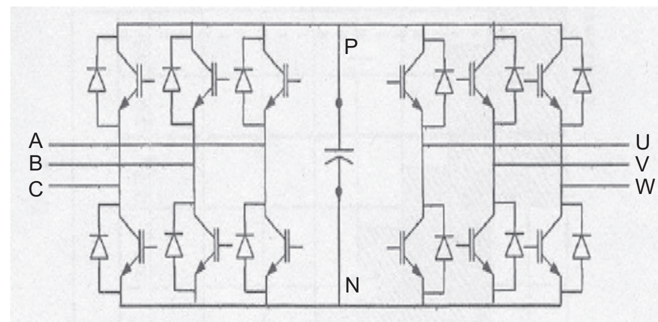

Fig. 4. Topology of BIM.

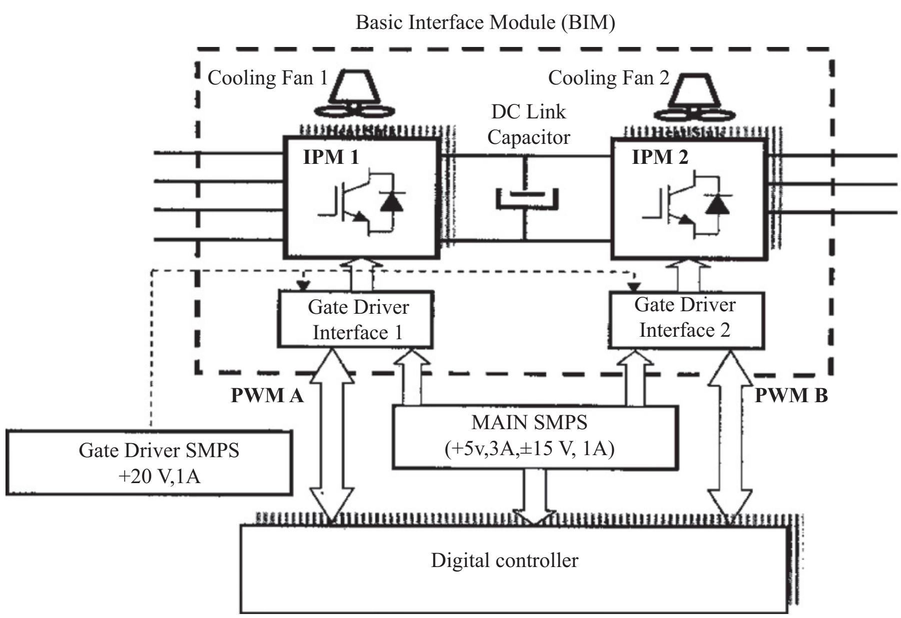

Fig. 2. Scheme of BIM and digital controller for the grid-connected system at Moushuni Islands.

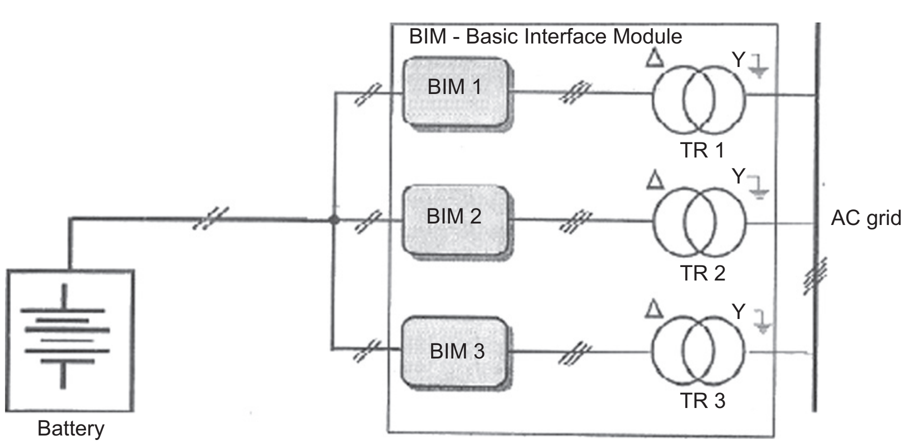

Fig. 3. Scheme of grid-connected system-an interface between grid and SPV array at Moushuni Islands [29].

operation is required bio-mass (variable frequency, variable voltage AC) on the input side.

8.6. Technical features

Technical features are as follows:

(i) maximum power point tracking for Wind Electric Generator (WEG) systems;
(ii) MPPT for solar PV panels;
(iii) parallel operation of load side inverters;
(iv) parallel operation of battery chargers.

8.7. Input side feature

The universal 10kW power electronic Basic Interface Module (BIM) with capability to interface with solar panels (variable current, DC), battery bank(fixed voltage, variable current, DC), wind generators (variable frequency, variable voltage AC), AC generator working from bio-mass(variable frequency, variable voltage AC) on the input side.

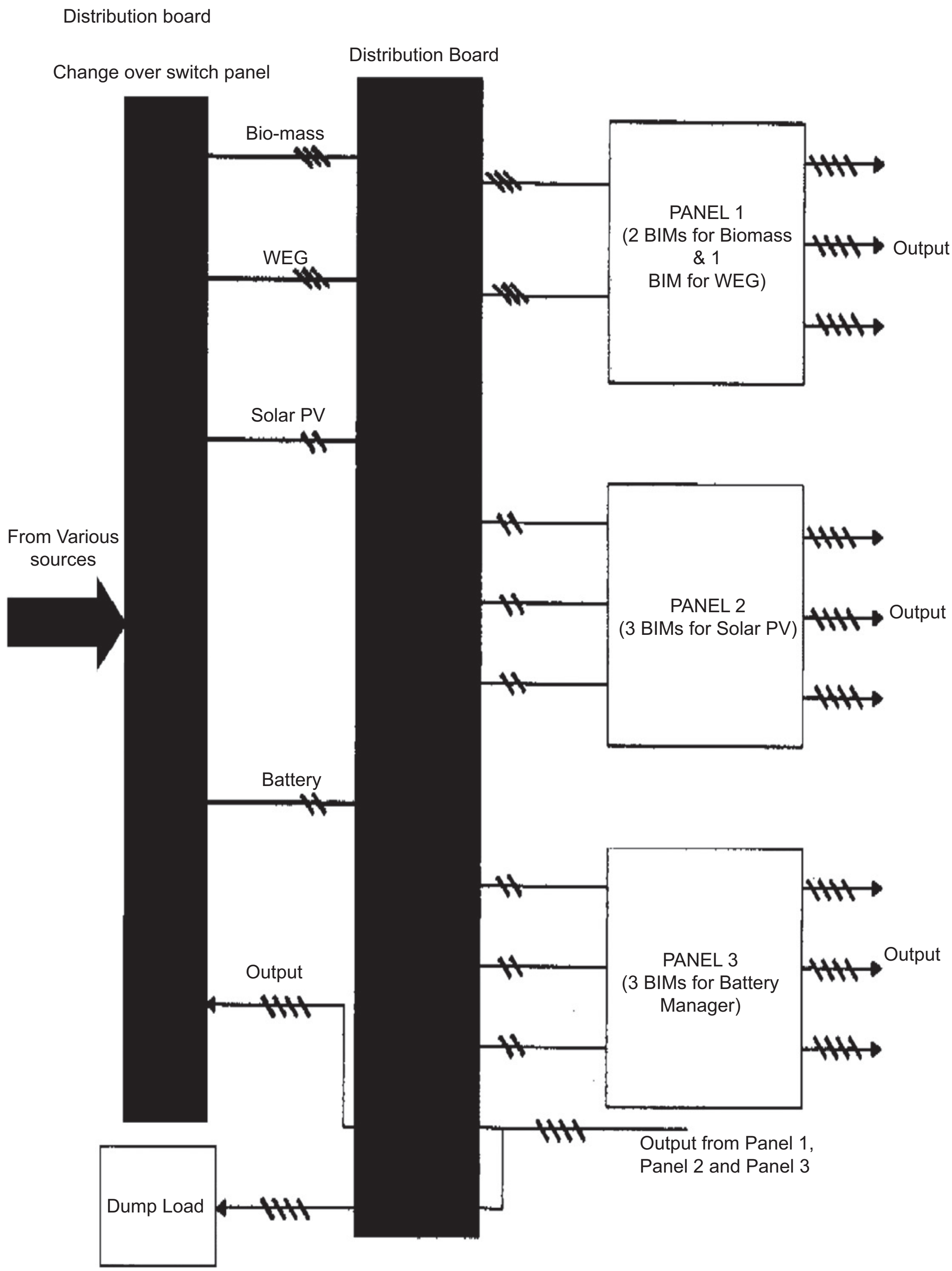

Fig. 5. Assembled and tested units of most intelligent controller.
(*Source*: WBREDA).

8.8. Output side features

The fixed frequency, fixed voltage AC link on the output side.

8.9. Control algorithm

The control algorithm will ensure integrated operation of all the interface modules connected in parallel so as to feed a 20 kW load ($_{\text{Max}}$), to the feeder. Specific modules will be programmed with suitable control algorithms, which can be used to extract maximum power from a SPV source or WEG. A central controller is proposed to ensure the integrated operation of the power system and to realize user interface (See Fig. 2).

9. Block diagram for digital controller, bim, topology of bim proposed to be installed at Moushuni Islands of West Bengal, India

9.1. Basic interface module (BIM)

BIM is a back-to-back, three limb, two-level Voltage Source Inverter (VSI) topology sharing a common DC bus. This basic module can be customized through controls to fit the interfacing requirements of the known sources of renewable energy (See Fig. 3).

9.2. Topology for BIM

A four-wire topology needs to be used. As the BIM is proposed to have a three-limb topology, the four-wire AC output is to be realized through delta-star coupling transformers (See Fig. 4).

10. Grid interactive operation of spv system at WBREDA

Operations: (1) the front end hardware module is tested as an interface between grid and solar PV array; (ii) the DC–DC converter of the BIM is controlled to extract power and transfer it to the intermediate DC link of the BIM; The front end inverter maintains the DC link voltage at 400 V and exports power to the grid at UPF.

Salient features of grid interactive operation of SPV system: grid connected front end inverter; Current control of source side converter with MPPT; power export at Unified Power Format (UPF); Fig. 5 anti-islanding protection.

Table A1
Projected Population with Growth Rate & Energy Demand of Malda district in W.B-India [26,27].

Char village	Population			
	Growth rate	2009	2011	2021
Harutola	2.58%	220	231.4984408	298.6585949
Khatiakana		316	332.5159422	428.9823454
Mangadpur		227	238.8643003	308.1613684
Janki sorkar		222	233.6029721	301.3736731
Sripur		211	222.02805	286.4407433
Hallas tola		174	183.0942214	236.2117978
Katlamary		183	192.5646121	248.4296494
Jugal tola		284	298.8434418	385.5410953
Sibu tola		204	214.6621906	276.9379698
Jamai para		122	128.3764081	165.6197663
Naya gram		273	287.2685197	370.6081655
Charbabu pur		169	177.8328932	229.4241025
Napitpara		277	291.4775823	376.0383218
Jitentola	2.05%	178	185.3728045	227.0785492
Gudurtola		158	164.5443995	201.5641055
Raghunathtola		309	321.7988573	394.1981557
Aaikattola		207	215.5739918	264.0744927
Master tola		145	151.0059363	184.9797171
Jagabandhu		391	407.1953178	498.807375
Jadutola		421	438.4379253	537.0790406
Raghu tola		157	163.5029793	200.2883833
Bhabani tola		130	135.3846325	165.8438843
Sadhucharan tola		217	225.9881943	276.8317145
Samastipur		339	353.0414648	432.4698213
Paschimnarayan pur		344	358.248566	438.8484322
Kartik tola		232	241.609498	295.9675473
Chabilaltola		283	294.7219308	361.0293788
Sonar tola		188	195.787007	239.8357711
Nathuram tola		236	245.775179	301.0704361
Rekha tola		255	265.5621638	325.3091576
Lalmohan tola		243	253.0651208	310.0004914
Ramananda tola		140	145.798835	178.6011061
Natun tola		142	147.8816755	181.1525505
Raghubirtola		157	163.5029793	200.2883833
Fulchand tola		176	183.289964	224.5271049
Someswar tola		192	199.952688	244.9386599
Sankar tola		126	131.2189515	160.7409955
Fuluktola		211	219.7396728	269.1773814
Amirchandtola		254	264.5207435	324.0334354
Bipin tola		231	240.5680778	294.6918251

Table A2
Estimation of Latitude, Longitude, and Elavation for each block, gram panchayet under each village of the Malda district in West Bengal, India [26,27].

Char Village	NASA surface meteorology and solar energy data		Elevation (ft)
Harutola	Latitude	Longitude	
Khatiakana	24°55′01.45″n	88?01′20.86″e	93
Mangadpur	24°55′17.99″n	88?02′45.23″e	69
Janki sorkar	24°57′08.45″n	87?57′15.32″e	97
Sripur	24°54′06.43″n	87?57′19.39″e	75
Hallas tola	24°53′46.48″n	87?57′19.39″e	78
Katlamary	24°52′16.43″n	87?57′19.39″e	88
Jugal tola	24°51′26.53″n	87?57′19.39″e	85
Sibu tola	24°55′01.40″n	87?52′15.37″e	92
Jamai para	24°56′04.00″n	87?59′33.94″e	76
Naya gram	24°57′05.08″n	87?57′39.98″e	84
Charbabu pur	24°55′08.27″n	87?51′11.45″e	75
Napitpara	24°55′08.27″n	87?51′11.45″e	69
Jitentola	24°55′01.41″n	87?52′12.47″e	97
Gudurtola	24°03′47.50″n	87?53′12.36″e	95
Raghunathtola	24°13′01.55″n	87?57′20.36″e	85
Aaikattola	24°15′06.48″n	87?57′25.26″e	79
Master tola	24°55′01.45″n	87?57′12.36″e	81
Jagabandhu	24°55′04.40″n	87?57′39.90″e	88
Jadutola	25°50′53.61″n	85?57′37.36″e	79
Raghu tola	25°55′43.55″n	86?55′42.46″e	75
Bhabani tola	25°51′41.50″n	87?56′47.26″e	81
Sadhucharantola	24°00′42.74″n	87?57′88.06″e	84
Samastipur	24°05′41.75″n	87?57′12.36″e	97
Paschimnarayan pur	25°04′43.61″n	87?47′09.37″e	85
Kartik tola	25°12′58.50″n	87?48′40.51″e	82
Chabilaltola	25°12′58.50″n	87?48′40.51″e	83
Sonar tola	24°55′25.57″n	87?57′06.73″e	75
Nathuram tola	24°49′26.38″n	87?58′13.61″e	90
Rekha tola	24°55′01.45″n	87?57′12.36″e	76
Lalmohan tola	24°55′31.35″n	87?51′11.26″e	77
Ramananda tola	24055′21.55″n	87?58′42.66″e	78
Natun tola	24°55′31.35″n	87?52′32.46″e	94
Raghubirtola	24°?52′22.45″n	87?50′13.66″e	85
Fulchand tola	24051′07.45″n	87?51′17.76″e	87
Someswar tola	25°11′56.40″n	87?55′16.39″e	79
Sankar tola	25°04′40.70″n	87?51′12.52″e	78
Fuluktola	24°55′01.35″n	87?57′12.36″e	87
Amirchandtola	24°55′23.45″n	87?57′12.36″e	86
Bipin tola	24°51′01.45″n	87?57′12.36″e	85
	24°45′01.34″n	87?51′08.26″e	83

Testing of battery manager panel: the battery manager was tested in the charging mode, where charging was performed both in constant current mode and constant voltage mode.

Inverter operation: the battery manager, in discharging mode, will generate AC voltage as per a command and reference given by the central control unit. Similarly, the frontend inverter of solar PV interface works in the same manner. The reference is a sinusoidal template for each output phase of the inverter. Inverters in the BIM should generate the same voltage and they should share the load current when they are working in parallel. Each hardware panel consists of three BIMs and therefore three inverters in parallel at the front end or load side.

11. Case analysis of energy study in selected Char villages of Malda district of West Bengal, India to set up a solar power plant-smart-grid city

The energy Study in Selected Char villages of Malda to set up a solar power plant to integrate it to the conventional electricity grid with the projected findings of current and future energy demand synchronized with the current and future population along with their growth rate percentage in 2009, 2011 and 2021 respectively (See Appendix A for Surveyed Data).

12. Conclusion

Renewable energy sources and batteries are inherently modular and can be upgraded when the long-term load demand increases, without changing the overall configuration of the system. Power electric converters, such as inverters, PV charge controllers, or battery chargers, should be sized such that an anticipated increase in load demand does not exceed their rated capacity. The local network of distributed hybrid renewable energy resources in case of usage of solar, biomass, wind power, can be integrated to the nearest conventional power grid, rather than extending the conventional power grid to the remote islands as in case of Moushuni Islands of Sundarbans of West Bengal eastern part of India. A universal interface for hybrid renewable energy sources with technology for integrated operation is required for this mini-grid integration to the nearest conventional power grid. Thus sustainability can be achieved through extending mini-grids to the national grid through regional grid. Proposed Malda District of West Bengal, India for rural electrification in Appendix is project by WBREDA towards rural electrification which can be a vision of smart-grid city towards sustainable future, where rural consumers can develop their quality of life through solar energy resource.

Acknowledgment

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Appendix

Following is the surveyed and tested data for villages under Malda District of West Bengal (W.B.), India for the project of rural electrification by WBREDA under Solar Mission as: (i) Table A1 provides projected population and energy demand by that population with growth rate percentage in the years 2009, 2011 and 2021 respectively at each village at gram panchayet and block level of Malda; (ii) Table A2 refers to sstimation of Latitude, Longitude, and Elevation in details for each block, gram panchayet under each village of the Malda; (iii) Table A3 refers to estimated solar radiation at a particular Latitude 25 and Longitude 87 provided as a sample at a particular point of the above mentioned Malda along with, details of climate data at that location of earth throughout the year; (iv) Table A4 refers, to control the market price of renewables in socio-economic parameters of Malda using Algorithm of Acceptance Index(AI)[25–28]; (v) Table A5 is system study for modernization of distributed systems at sagar islands–load demand survey for domestic consumers [29].

Table A3
Sample of climate data estimation of solar radiation [26,27].

Sample of NASA Surface Meteorology and Solar Energy Data for Eastern part of India,Malda District of West Bengal

			Unit	Climate data location				
Latitude			°N	25				
Longitude			°E	87				
Elevation			m	37				
Heating design temperature			°C	12.70	NASA Surface meteorology and solar energy:RET screen data			
Cooling design temperature			°C	31.26				
Earth temperature amplitude			°C	15.95				
Frost days at site			day	0				
Month	Air temp. (°C)	Relative humidity (%)	Daily solar radiation-horizontal (kWh/m^2/d)	Atmospheric pressure (kPa)	Wind speed (m/s)	Earth temp. °C	Heating degree-days (°C-d)	Cooling degree-days (°C-d)
January	17.6	47.9	4.25	99.3	1.7	19.3	27	237
February	20.7	43.5	5.30	99.1	2.1	23.5	2	302
March	25.1	40.4	6.27	98.7	2.1	28.8	0	465
April	26.6	58.0	6.70	98.4	2.6	29.8	0	499
May	26.6	76.8	6.51	98.2	3.0	28.8	0	517
June	27.6	82.9	5.39	97.8	2.9	28.9	0	527
July	27.4	85.7	4.39	97.9	2.5	28.3	0	538
August	27.4	84.9	4.44	98.0	2.1	28.1	0	539
September	26.3	84.3	4.12	98.4	2.0	27.0	0	493
October	24.2	76.9	4.86	98.8	1.6	24.9	0	450
November	21.6	57.5	4.72	99.2	1.6	22.3	0	359
December	18.9	49.3	4.17	99.4	1.6	20.1	7	284
Annual Measured at (m)	24.2	65.7	5.09	98.6	2.1	25.8	36	5210
	–	–	–	–	10.0	0.0	–	

Table A4
Socio-economic parameters of Malda district in West Bengal, India [26,27].

Village	Name	Panchanandapur	JamaiPara	JamaiPara	PeyariPola	Mangadpur
Geographical Area	sq. km					
Gram Panchayet	name	Panchananda pur	Panchananda pur	Panchananda pur	Panchananda pur	Hamidpur
Population-Male	nos.					
Population-Female	nos.					
Population-Total	nos.	240	126	126	146	218
Population-School Going Children	nos.	80	36	36	46	35
Population-SC	nos.	126	126	101	95	
Population-ST	nos.					
Population-Lit. Male	nos.	75	29	29	55	40
Population-Lit. Female	nos.	46	21	21	44	21
Population-Lit. Total	nos.	121	50	50	99	61
Population-Agri /lab	nos.	45	23	23	29	42
Population-Fishing	nos.	0	1	1	0	0
Population-Others	nos.	0	2	2	0	1
Population-Working Total	nos.	45	26	26	29	43
Total Income rs.	59000	32700	32700	38800	63700	
No of Families	nos.	45	26	26	29	43
Avr. Income per Family	rs.	1311	1258	1258	1377	1481
Average monthly fuel requirement						
(a) Kerosene	litres	4.7	2.9	2.9	4.9	5.04
(b) Fuel wood	kg	115.5	85.3	85.3	93.1	172.5
No. of points required						
(a) Fan	nos.	55	47	47	30	71
(b) Light	nos.	113	60	60	59	103
(c) TV	nos.	18	19	19	3	34
Electrical load						
(a) Fan (@ 60 W each)	kw	3.3	1.9	1.9	1.2	2.84
(b) Light	kw	11.3	6	6	5.9	10.3
(c) TV	kw	4.3	4.5	4.5	0.72	8.16
(d) Total	kw	18.9	12.4	12.4	7.82	21.3
(e) Summer (3 h/day for 6 months)	kwh/month	9612	6696	6696	4222.8	11502
(f) Winter (3 h/day for 6 months)	kwh/month	9612	6696	6696	4222.8	11502
(h) Total (S:1602; W:1602)	kwh/year	19224	13392	13392	8445.6	23004

Table A5
System study for modernization of distributed systems at Sagar Islands—load demand survey for domestic consumers [29].

Ref. Location	Rudra nagar Bazar	Rudra nagar Bazar	Rudra nagar Bazar	Rudra nagar Bazar	Rudra nagar Bazar	Rudra nagar Bazar
Name of establishment	Com.	Com.	Com.	Com.	Com.	Com.
Source of supply	W.B. S.E.B. (1X25 kVA Tr)	W.B. S.E.B. (1X25 kVA Tr)	W.B. S.E.B. (1X25 kVA Tr)	W.B. S.E.B. (1X25 kVA Tr)	W.B. S.E.B (1X25 kVA Tr)	W.B. S.E.B. (1X25k VA Tr)
Connected load						
Light		2T+3B	2T+2B	5B	10T+2B	8T+3B
Fan		2	1	–	2	2
TV		–	–	–	–	–
Freezes		–	–	–	–	–
Others		1X5A Plug	2X5A	1X5A	1X5A 1X1.5 kW Motor	1X5A
Total load in kW	0.6	0.58	0.54	0.48	2.86	0.88
Demand load in kW	0.3	0.39	0.29	0.31	0.89	0.63
Willingness for power A: very willing B: somewhat undecided C: unwilling		A	A	A	A	A
Preferred supply time A: 24 h supply B: fixed time supply C: any time supply		A	A	A	A	A
Possible of expansion of business with increased availability of power		Yes	Yes	Yes	Yes	Yes

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Further reading

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